September 1943 AIC-23

INFORMATION SHEET ON
ANALYSIS OF PROCESSING COSTS IN VEGETABLE DEHYDRATION

Western Regional Research Laboratory, Albany, California
Bureau of Agricultural and Industrial Chemistry
Agricultural Research Administration
U. S. Department of Agriculture

Processing costs in vegetable dehydration depend on two factors: the unit costs for materials and service and the degree of success in achieving the most economical processing procedures. Labor, material, and building costs are frequently determined by factors not under the control of the operator. Several expedients are used, however, to modify these fixed conditions. The plant operator may employ women instead of men, thus taking advantage of the lower wage rate; he may grow his own vegetables at a cost more directly under his control; and he may sometimes use second-hand buildings and equipment at a fraction of new costs. He is more or less dependent upon outside conditions for the material and services available, but he must determine, on his own initiative, the combinations of these that produce the best results.

The factors under management control can be divided again into two groups: those that are largely fixed when the building is completed and operations started and those that are variable and develop as operations continue. These are as follows:

Fixed after operations begin:
- Plant layout and design
- Process installed

Variable:
- Grade, variety, and condition of raw material
- Yield of dry product from raw material
- Efficiency in the use of labor and equipment
- Continuity of operations

These factors may overlap in several instances, but will be discussed in the order indicated in order to facilitate further analysis.

Plant layout and design.--The type of building, kind and size of equipment, and plant layout have a very decided effect on the efficient operation of any dehydration plant. A plant that is not set up to make the most efficient use of labor, equipment, and floor space, and to handle raw materials without damage and waste, may have prohibitively high operating costs.

Adequate space must be provided for all operations, in order to avoid crowding. Raw product may spoil if raw storage is not well ventilated and cool. Workers along the trimming belt cannot work efficiently if the space allotted to them is insufficient for freedom of movement. Excessive handling of cars and trays will be required if adequate space at the dehydrators is not provided for movement and storage of cars. Ease of handling the equipment and the product is an important consideration.

Cross-flow of traffic may cause much lost time and inconvenience, and excessive hauling distances for material and employee travel are likewise inefficient. The production lines should be set up for a minimum of handling of the product at all stages. This is particularly true of the leafy raw vegetables which do not handle well on elevators or conveyors. Provision should be made for an orderly and economical disposal of wastes.

Ample capacity in the drying equipment is imperative. Discussions of operating costs usually assume a balance between the preparation line and the dehydrator. Obviously, the balance is disturbed by anything that changes the capacity of the preparation line or the dehydrator. Suppose, for example, that the output of the preparation line is increased as a result of improvement in raw material, thus increasing the amount of material fed to the dehydrator. If the dehydrator has reserve heating capacity, it may be possible to dry the increased quantity by decreasing the amount of air recirculated, thus shortening the drying time. The alternative expedient of increasing tray loading may be undesirable from the standpoint of product quality because of increased drying time and, for the same reason, may not increase the quantity of material the dehydrator will dry in a given period of time. The increase in fuel cost due to lower heat efficiency will usually be more than offset by the value of the increased output of the plant. In other words, if there is no shortage of fuel, fuel economy is relatively less important than labor efficiency.

The size of the plant is one of the more important factors influencing processing costs. Because of the need for at least one or more employees for each of many operations regardless of the throughput at those points, the smaller plants are at a disadvantage as compared to the larger ones which can make more efficient use of labor. Other factors also tend to increase the costs in small dehydration plants, such as the less efficient use of equipment which is available in larger sizes only, the relatively higher operating charges on the smaller machines, and the lesser degree of mechanization. A comparison of probable labor costs in dehydration plants of various sizes is shown in Figure 1.

All of these points are important in designing and laying out a dehydration plant. Their effect on the total capital cost is relatively less than on the efficiency of daily operations. It is therefore important to lay out a plant in a manner that keeps operating costs down even if the capital investment is increased somewhat. The most economical balance is undoubtedly found in a plant with relatively high initial cost.

Process installed.--The process installed affects processing costs in four major ways: (1) output of plant, (2) labor required to operate the process, (3) yield of dry product from raw material, and (4) other operating costs such as fuel, power, etc. The output of the plant is more important from an operating standpoint than from a capital investment standpoint. Unless the initial cost of the process equipment is unduly high, the capital charges on the investment are relatively minor. The main objective is to install a process that gives a balanced operation between labor, capital, and available raw material.

The amount of labor varies widely according to the process installed. For example, a truck-and-tray, tunnel dehydrator handling about 50 tons per day of raw product may require as many as 10 to 15 employees in drying and related operations alone. A continuous type of drier, such as a conveyor, may require less than 5. Such a difference in the hourly labor costs will offset a considerable capital investment. Figure 2 shows roughly the amount of equipment that can be purchased and operated by specified savings in labor costs. The accompanying Table 1 gives the details of the calculations. A decrease in labor costs of only one dollar per hour will pay the operating and capital charges on a machine costing $4,000, using a five-year write-off. It is interesting to note that as the write-off period increases, the amount of additional equipment justified by a given labor saving increases but at a slower rate.

Installation of all possible labor-saving devices is a further means of reducing operating costs when the general process and major items of equipment have been decided upon.

The decision to install an abrasive peeler, a lye peeler, a flame peeler, or a hot liquid peeler should not be made on the basis of original investment. The probable preparation losses and the required trimming labor are more important and should be weighed heavily in reaching the decision. Possible damage to the product is also a factor in some cases.

If the equipment is properly designed, the actual operating charges on machines will usually be small enough so that they will be of relatively minor importance in determining the choice of process and equipment.

Grade, variety, and condition of raw material.--As a rule, raw material is the largest single item of cost in vegetable dehydration. In some instances, it may amount to as much as 50 percent or more of the total cost per dry pound. Any attempt to reduce operating costs should, therefore, include careful study and control of the raw material. Variety, growing conditions, time of harvest, handling, and storage, all of which affect the quality of the raw product, are extremely important in determining costs, yield, and quality of the dry product. An operator should contract for his raw material well in advance of actual need, so that the production, transportation, and storage will be under his direct supervision and the product delivered to him will be the best obtainable.

The cost of raw product is magnified in the cost of the dry product to the extent of the overall shrinkage ratio. [1] Figure 3 has been prepared to show this relationship. On cabbage, a cost increase of only a dollar a ton results in an increased cost of about one cent per dry pound. On a given vegetable, the quality and condition of the raw material will determine largely the overall shrinkage ratio. It is advisable in many cases to pay relatively

---

[1] The "overall shrinkage ratio" is the ratio of the weight of unprepared raw material to the resultant weight of finished product. The "drying ratio" is the ratio of the weight of material entering the drier to the weight of material leaving the drier.

high prices in order to obtain high-quality vegetables, since lower preparation losses and frequently lower drying losses will increase the yield and more than offset the higher purchase price. Figure 4 shows the effect of preparation losses upon the cost of the prepared product. 2/

Figure 5 illustrates the effect of the trimming rate upon the cost of preparing the vegetables for drying. Above a trimming rate of 200 pounds per woman hour, changes in rate have relatively little effect upon trimming cost per pound of material. Below that point changes in trimming rate have an increasingly important effect on trimming cost. It is under these conditions that peeling and trimming are among the most important operations to watch.

A careful analysis of the interrelated variables, raw material grade, preparation losses, trimming costs, and drying ratios, is essential if the most economical combination of raw materials and preparation methods is to be attained. Charts such as those shown in Figures 6 and 7 can be conveniently used to study the combined effect of these variables. For example, we find from Figure 6 that a raw material which has a 20 percent preparation loss 2/ and a 5 to 1 drying ratio yields 320 pounds of dry product per raw ton. If the combined raw material and trimming cost is $60 per unprepared ton, we find from Figure 7 that the cost per dry pound is 19 cents. If a cheaper material, costing only $48 per ton in spite of higher trimming costs, is found to have a 30 percent preparation loss and a 5-1/2-to-1 drying ratio, the charts indicate that this material also costs 19 cents per dry pound for raw material and trimming. Quality of final product may be the deciding factor in this case if waste disposal is not an important problem and the labor supply adequate. The operator will find that similar graphs are applicable to other operating problems.

Certain assumptions must be made and some caution exercised in the use of such graphs. For the purpose of these illustrations, it is assumed that all changes in weight during preparation, either through loss of material or changes in water content, are included in the preparation loss.

When wood trays are used in the determination of preparation loss, errors may be caused by the variable tare weight of the trays, depending on the wetness of the wood. This difficulty can be largely overcome in test runs by wetting the trays before loading and using the weight of the wet trays as the tare weight. The problem is obviated by the use of metal trays.

The changes in weight from the raw material, as purchased, to the prepared material, ready for drying, include such items as dirt removed in preliminary washing, culls graded out, the actual preparation losses (peeling, coring, trimming, etc.), and leaching losses or water pickup during the peeling, cutting, washing, and blanching. Excessive washing after cutting and especially after blanching may result in losses of 10 percent or more on potatoes.

2/ The preparation loss used for this purpose must be an overall preparation loss, determined in actual test runs, and must take account of the possible sources of error discussed in the following paragraphs.

In test runs, the drying ratio should be determined on the plant-prepared material, ready to go to the dehydrator, rather than on small samples. Determination of drying ratios on samples of different raw materials is, nevertheless, a valuable means of making preliminary comparisons.

Inspection losses on the final product are frequently so small that they can be neglected. If inspection losses are large enough to warrant a correction on the yield, this correction can be made by a deduction from the yield shown by the graphs for given values of preparation loss and drying ratio. It may be impossible to determine this in advance of actual plant operations. If fines are removed from the dry product before packaging, they may be either a total loss or may have a market value at a lower price. This will require a further correction to the yield. The simplest procedure is to determine yield after removal of the fines and credit the operations separately with any return obtained from the sale of the fines.

Failure to take account of the many factors tending to decrease the final net packed weight may result in ruinously erroneous conclusions regarding the probable overall weight shrinkage from raw material to final product. Solution of the problem outlined above should, however, be relatively easy in an operating plant, since it can be based on actual operating tests.

A greater danger lies in the assumptions that are likely to be made in planning for a new plant where previous experience is not available on the raw material or process. The only data will be hypothetical figures, moisture content of the raw material, and estimated peeling and trimming losses, with perhaps allowances for inspection and screening losses. Suppose that a mixture of No. 1 and No. 2 potatoes is being used. The moisture content is found to be 78 percent, corresponding to a drying ratio of 4.3 to 1. The total loss from raw to finished product is assumed to be 25 percent, giving an overall shrinkage of 5.7 to 1. Few people would assume a loss of 39 percent, which would raise the ratio to the 7 to 1 value frequently found in actual operation on raw material of this character. The difference may lie in dirt and cullage losses and leaching losses during preparation or failure to use representative material in determining the moisture content.

Yield of dry product from raw material.--Careful treatment of the raw product through all stages of preparation reduces processing costs per dry pound by increasing yields. The three steps in preparation where proper control offers the best opportunity for decreasing material losses are peeling, trimming, and washing after cutting.

Most abrasive peelers have the tendency to overpeel smaller vegetables in mixed sizes and underpeel larger ones. It is preferable, therefore to put only one size at a time through this type of peeler. Proper control of liquid temperature and exposure time must be maintained in lye, brine, and similar types of peeling operations. Variations will usually result in increased losses of raw material. Overheating causes excessive abrasion and washing losses, and underheating causes heavy trimming losses.

The care and skill exercised by trimmers have an important effect on material losses. Proper training and supervision are especially important for trimming personnel. The plant operator should know at what point a further increase in trimming rates results in excessive raw-material losses. In a plant handling one ton per hour of raw product costing $40 per ton, a saving of only 5 percent of the raw product by slower and more careful trimming will pay for the employment of two extra employees if the hourly labor cost per employee is $1.00 including overheads. If the plant processes 5 tons per hour, 10 additional trimmers could be justified by a 5 percent material saving. (See Figure 8.)

The manner in which a machine is operated may cause variation in processing costs greater than the capital charges on the machine. For example, some cutters produce a considerable amount of chaff unless fed at optimum rate.

Excessive washing after cutting must be avoided. Nutritive values and yield are greatly reduced if the washing is too severe. Some operators have reported savings of 10 percent or more by reducing washing after cutting to a bare minimum.

<u>Efficiency in the use of labor and equipment</u>.--Equipment costs are important, but are usually small in the long run compared to the cost of labor displaced. Total labor may run as high as a third of all processing costs. Studies on labor efficiency and labor replacement offer a most promising means for effecting reductions in operating costs.

Increased output per employee may be achieved by proper training and intelligent supervision. A piece-work or bonus system, coupled with rigid supervision and inspection, usually results in lower labor costs, especially in the trimming operation. A reduction in the number of workers can often be made by more uniform operation, the elimination of process steps, or the installation of labor-saving equipment. The importance of the last point is sometimes underestimated, even in large plants.

The cost of heat and power for many products may not amount to over 1 cent per dry pound. Even though this expense is minor when compared to labor and material, considerable saving can be experienced by careful and proper operation of the drier. Allowable temperatures and humidities and optimum drying times are predetermined technologically. Within the range of these conditions, the plant operator must find the most economical point of operation.

Figure 9 shows the approximate cost of heat and power for evaporating water in an air-blast drier with various percentages of recirculation. It will be noted that minimum drying costs occur somewhere between 60 and 80 percent recirculation under most weather conditions. With high outside temperature and low relative humidity, the amount of recirculation has little effect on evaporating costs in the practical operating range. The value for fuel cost used in the charts corresponds to 24 cents per 1,000 cubic feet for high-B.t.u. natural gas.

Figure 10 illustrates the effect of outside weather conditions on drying costs.

As the amount of recirculation increases, the temperature and humidity of the outside air have decreasing effects on costs. High outside temperatures lower the drying costs if the relative humidity is low, but if the relative humidity rises, the costs also rise. This is the result of the increase in power costs brought about by the need to circulate much more air to evaporate the same amount of water.

Continuity of operations.--A uniform flow of product along the preparation line is essential for most economical operation. An even flow requires fewer employees and smaller equipment than does an irregular or spasmodic flow. Losses caused by temporary shutdowns are often large. Most items of cost continue during shutdowns with the exception of raw material and packaging supplies not used and a small amount of utilities. It may not be practical to save labor costs by dismissing the help, because it is often impossible to anticipate the length of a shutdown.

The amount of loss due to such a shutdown can be roughly estimated by assuming that the sale value of the lost product less the costs of materials saved, raw materials, and containers, is an actual loss. For example, a shutdown of the preparation line, due to a shortage of raw material, results in a loss of 20 cents for each pound of lost production if the selling price of the product is 35 cents per pound and the combined raw material and container costs are 15 cents per pound. This amounts to $100 per hour in a plant which normally turns out 500 pounds of finished product per hour. Figure 11 shows the amount of loss for various periods of stoppage.

FIGURE I
RELATION OF LABOR COST TO PLANT CAPACITY
IN VEGETABLE DEHYDRATION

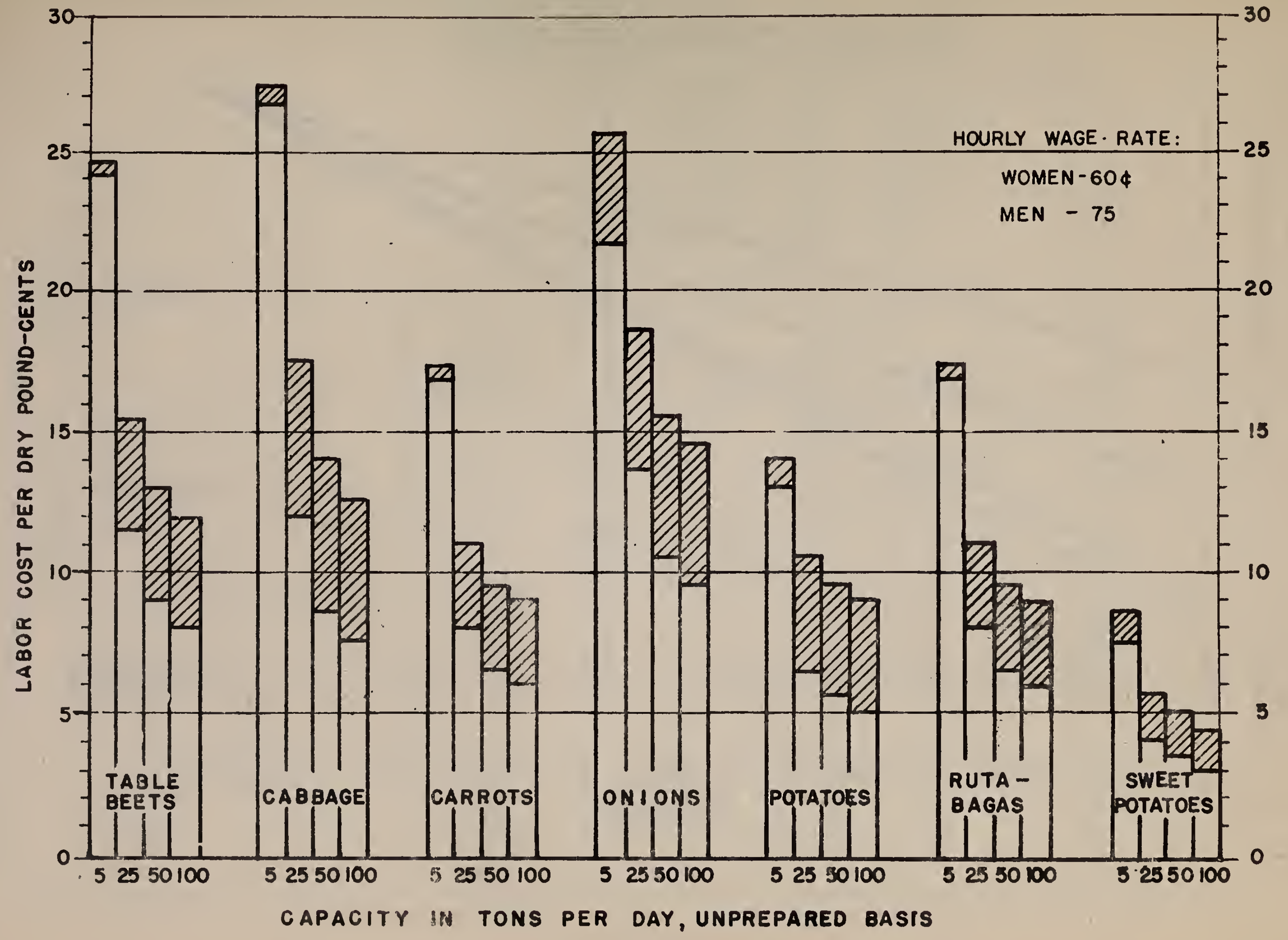


FIGURE 2
EQUIPMENT INVESTMENT JUSTIFIED BY SAVINGS IN LABOR COSTS

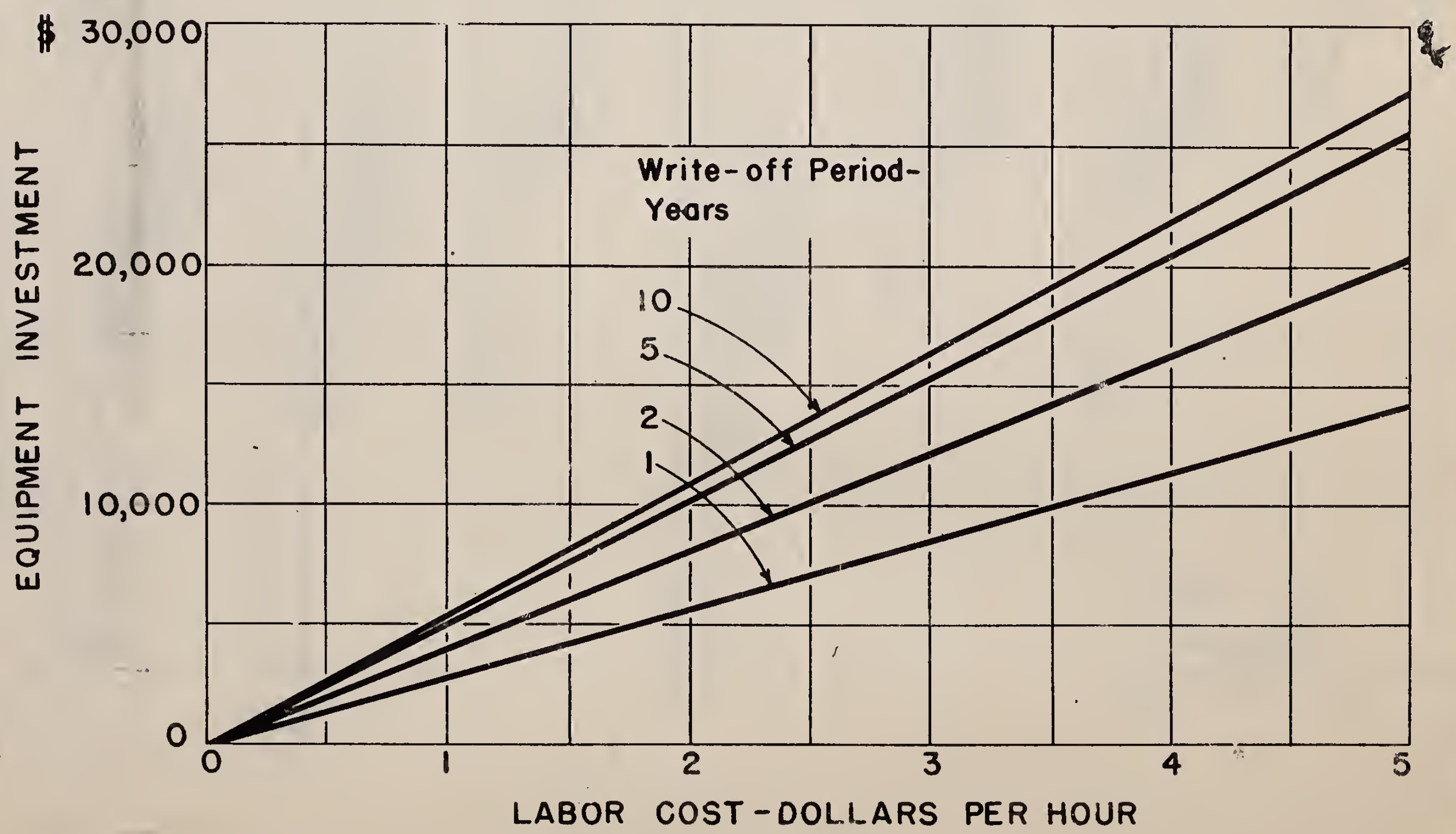


TABLE I.--Equipment investment justified by reduction of labor costs, assuming various periods of write-off for the equipment
(Assuming a 200-day operating season - 24 hrs. per day)

	Write-off period			
	1 year	2 years	5 years	10 years
Cost of equipment installed	$ 1,000	$1,000	$1,000	$1,000
Annual charges				
Depreciation	$ 1,000	$ 500	$ 200	$ 100
Repairs	(10%) 100	(10%)100	(15%)150	(20%) 200
Interest and taxes - 10% of investment	100	100	100	100
Total fixed annual charge per $1,000 investment	$ 1,200	$ 700	$ 450	$ 400
Divide by 200 days to get cost per day	$ 6.00	$ 3.50	$ 2.25	$ 2.00
Divide by 24 to get cost per hour	25¢	14.6¢	9.4¢	8.3¢
Add for hourly cost of operating machine per $1,000	10¢	10¢	10¢	10¢
Total charge per hour for equipment - or the amount of labor per hour that will buy $1,000 worth of equipment	35¢	24.6¢	19.4¢	18.3¢
Dollars of equipment bought by $1 worth of labor - (1,000 divided by the machine cost per hour)	$2,860	$4,070	$5,150	$5,460
Ditto for $5 labor	$14,300	$20,350	$25,750	$27,300

FIGURE 3

EFFECT OF OVERALL SHRINKAGE RATIO ON MATERIAL COST

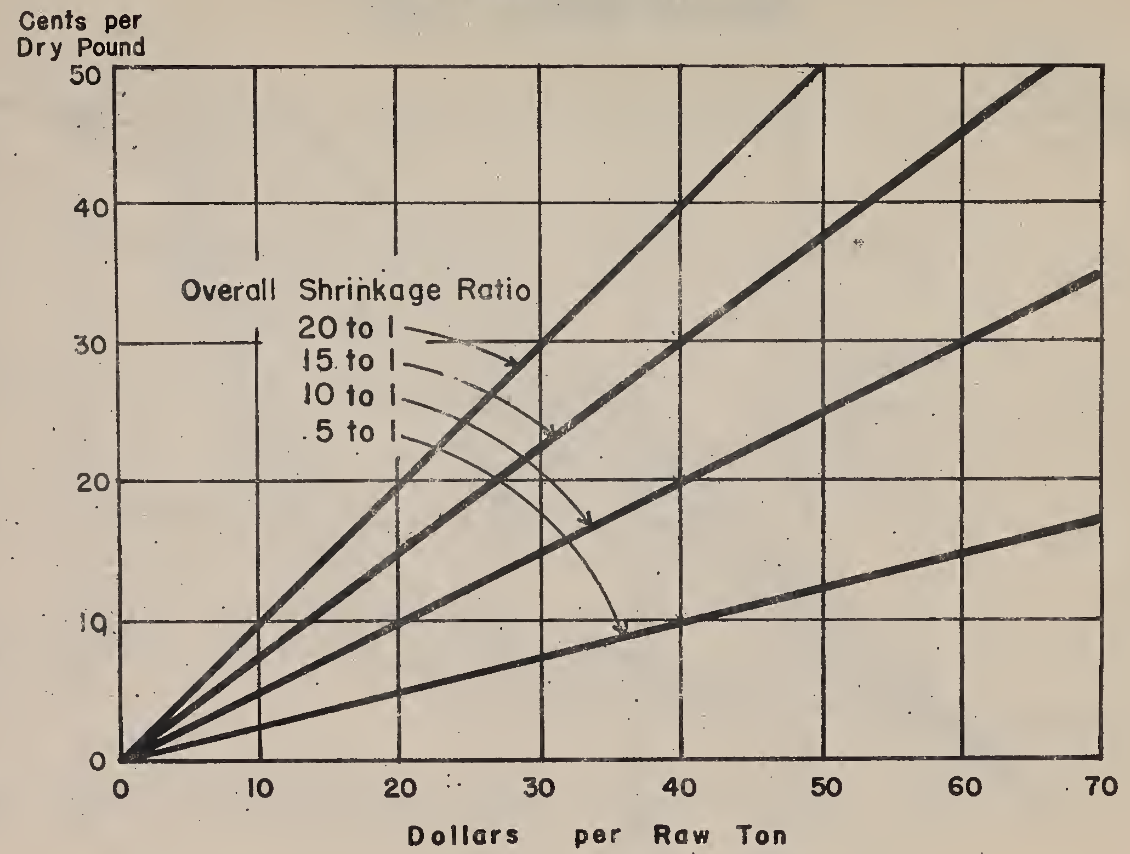


FIGURE 4

EFFECT OF PREPARATION LOSS ON MATERIAL COST

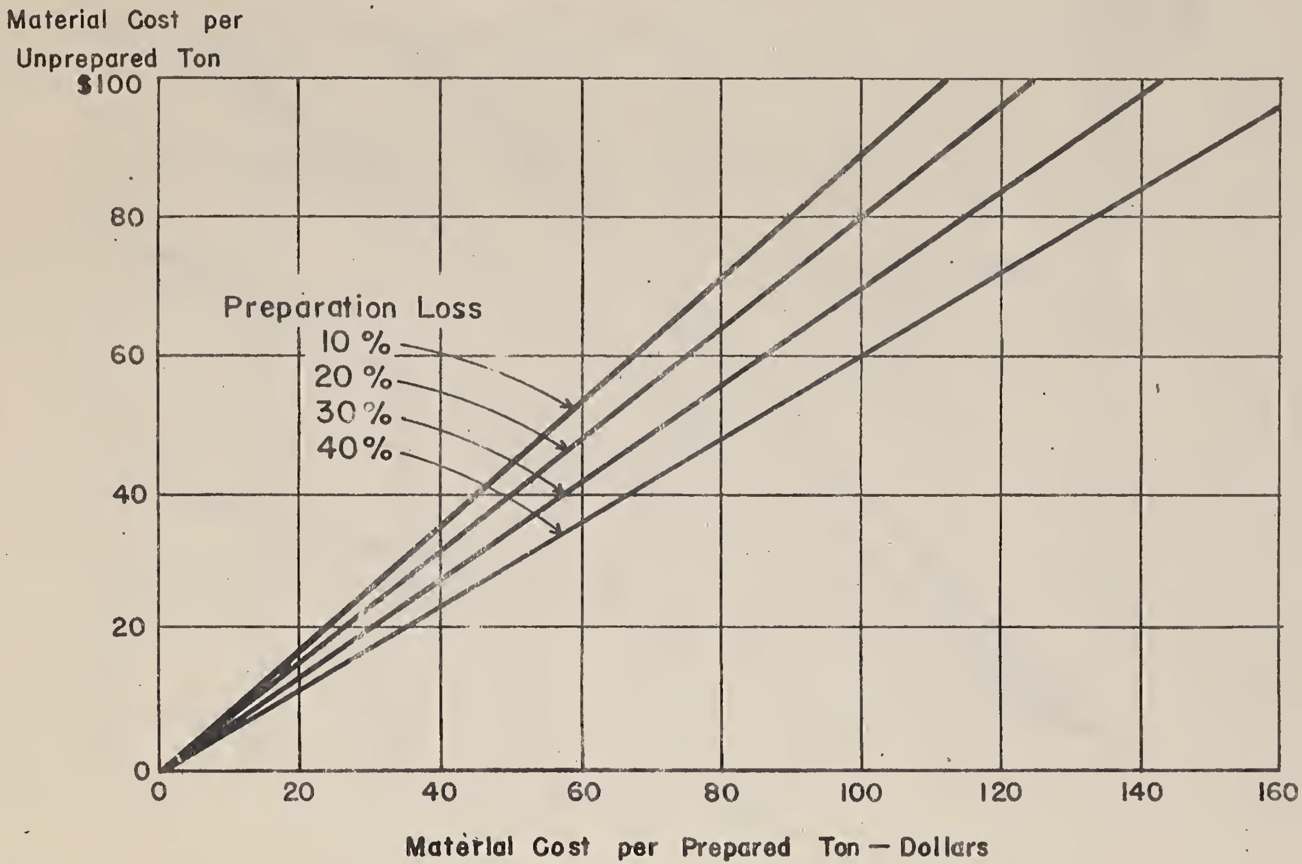


FIGURE 5

EFFECT OF TRIMMING RATE ON LABOR COSTS

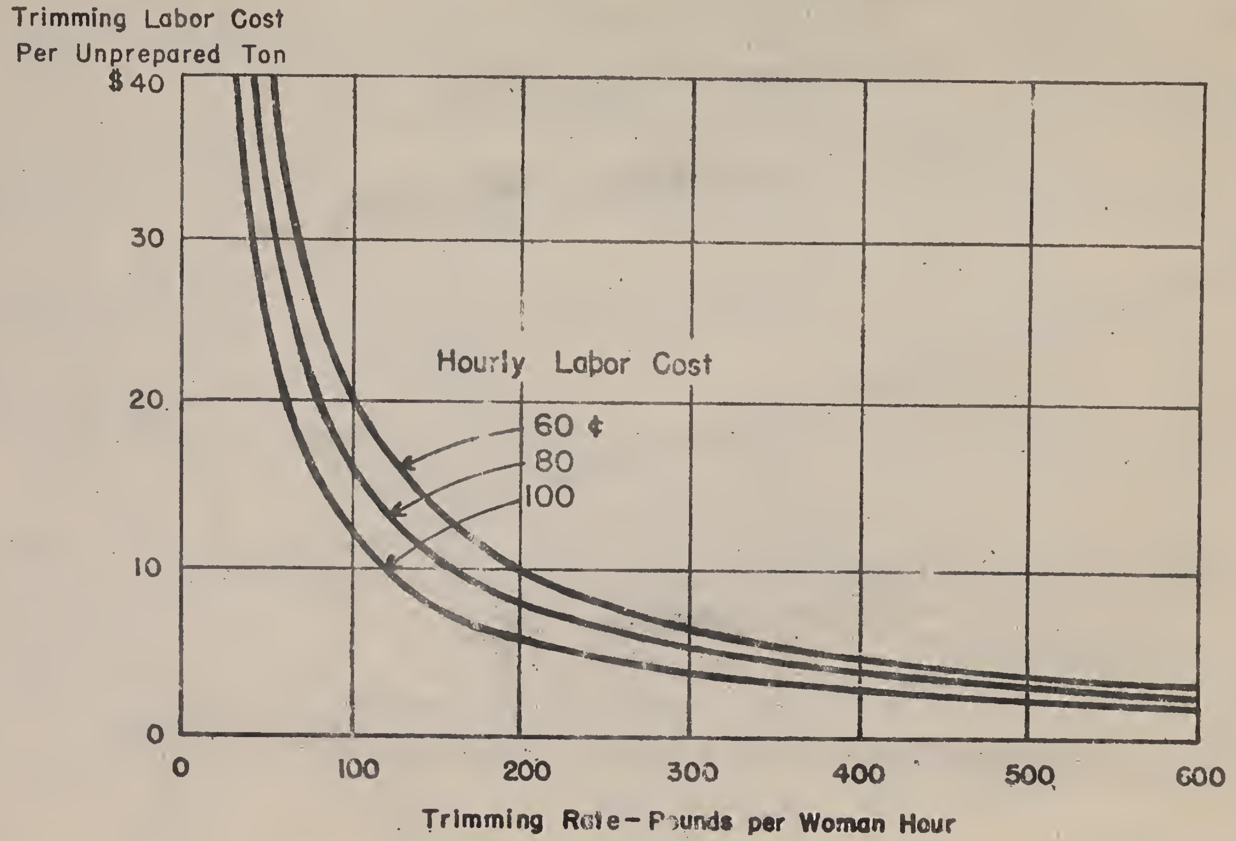


FIGURE 6

YIELD OF DRY PRODUCT AT VARIOUS PREPARATION LOSSES AND DRYING RATIOS

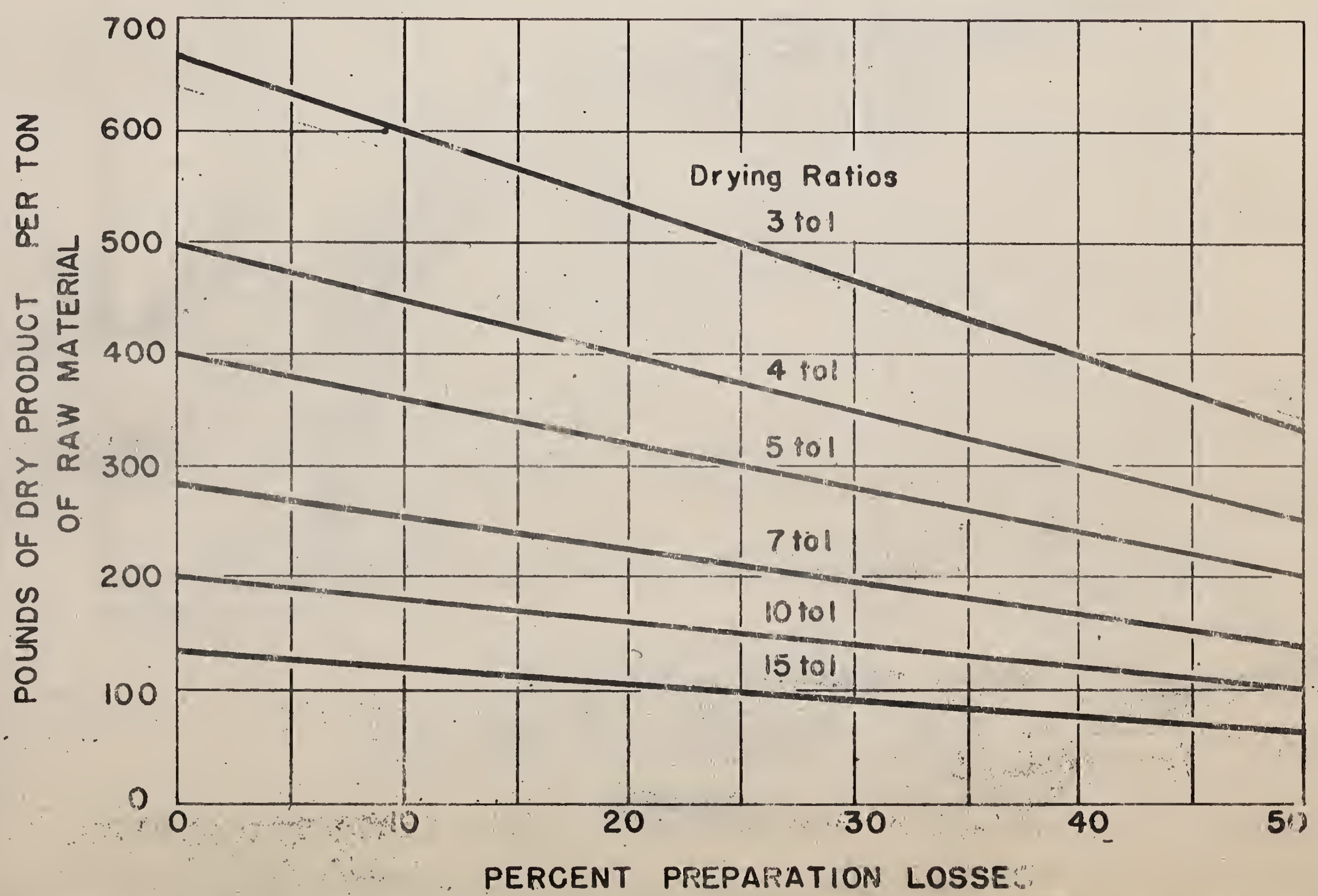


FIGURE 7
RAW MATERIAL AND TRIMMING COST PER DRY POUND

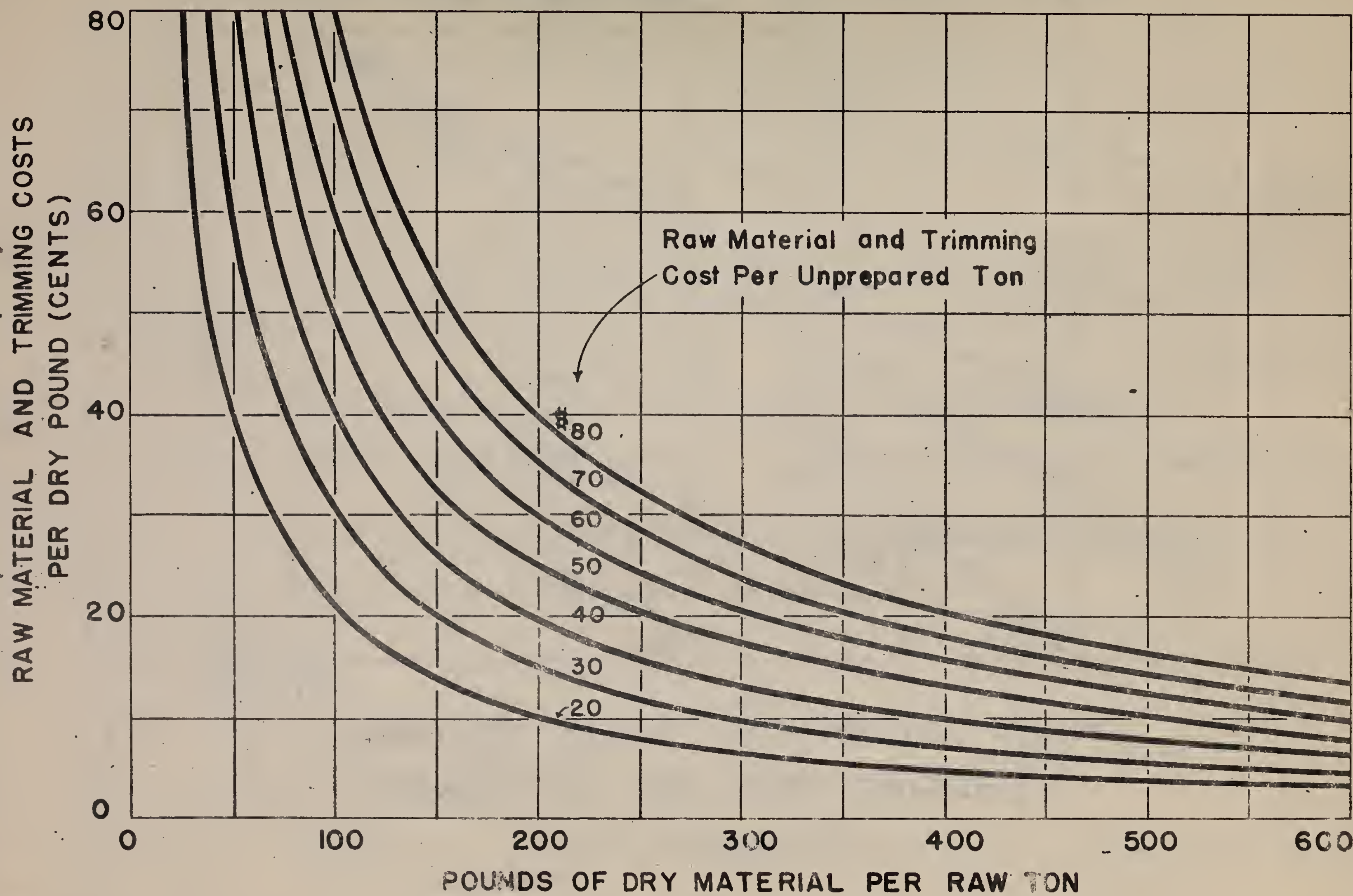


FIGURE 8

NUMBER OF ADDITIONAL EMPLOYEES JUSTIFIED BY A 5% RAW MATERIAL SAVINGS

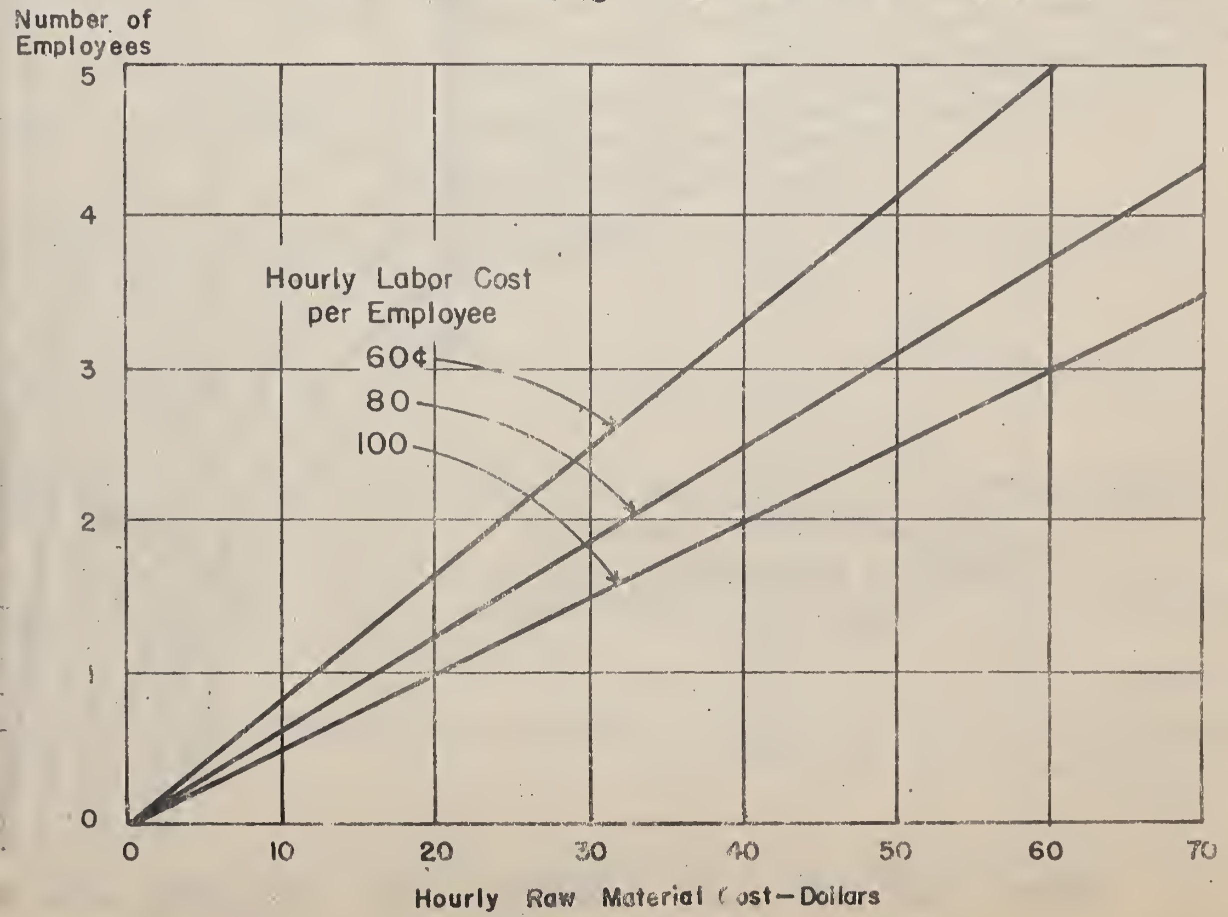


FIGURE 9 - EFFECT OF RECIRCULATION ON THE COST OF EVAPORATING WATER IN AN AIR-BLAST DRIER

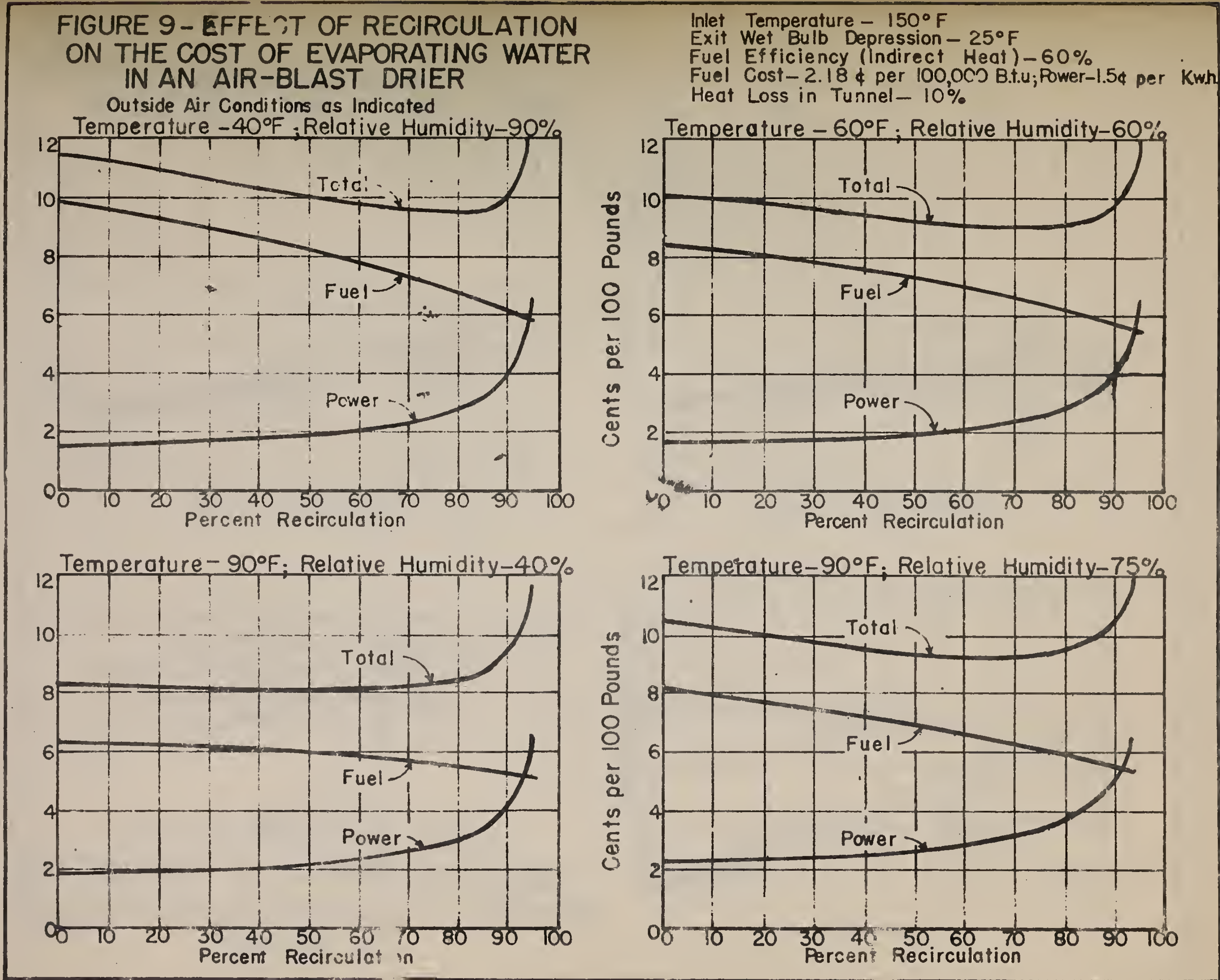
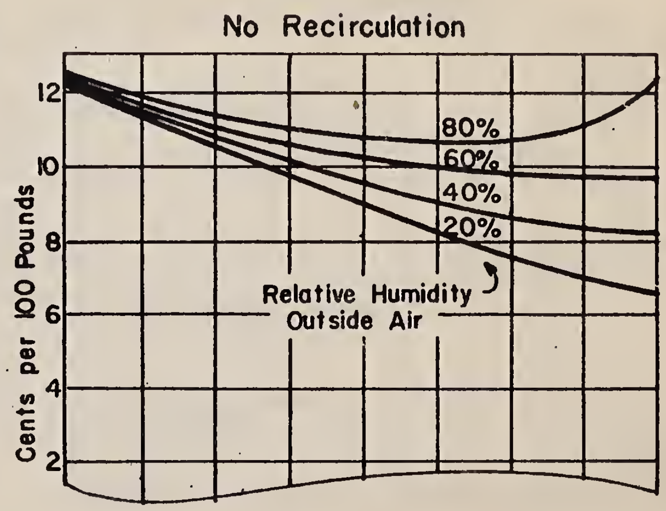
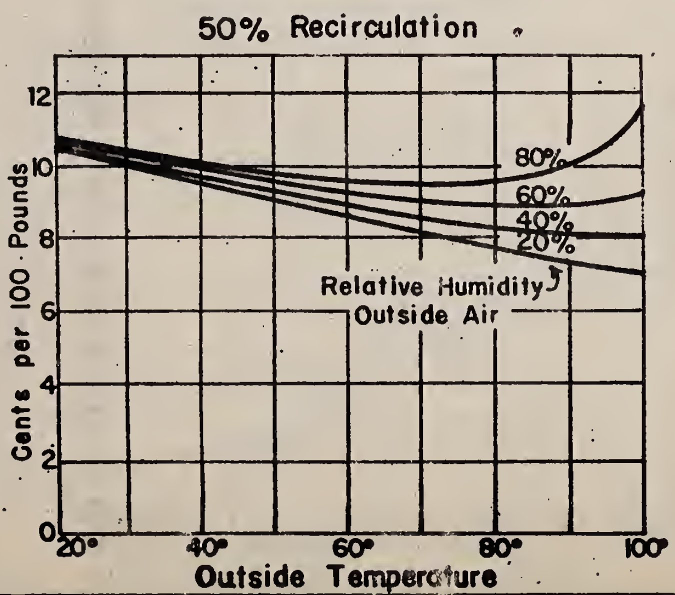


FIGURE 10
EFFECT OF OUTSIDE WEATHER CONDITIONS
ON THE COST OF EVAPORATING WATER
IN AN AIR-BLAST DRIER

Inlet Temperature– 150° F
Exit Wet Bulb Depression–25° F
Fuel Efficiency (Indirect Heat)– 60 %
Heat Loss in Tunnel–10%
Fuel Cost–2.18¢ per 100,000 B.t.u.; Power–1.5¢ per Kwh.





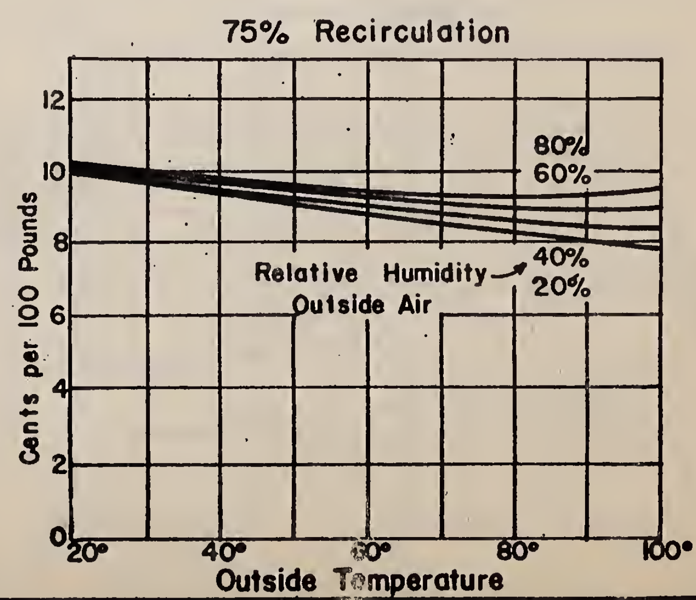


FIGURE 11

LOSS CAUSED BY SHUTDOWNS